

## Infra Bass

The invention relates to a bandwidth extension device as defined in the preamble of claim 1.

The invention further relates to an audio reproduction system comprising such a bandwidth extension device.

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Such a device is known from the European patent application EP-A-0240286. To improve the aural sensation in low-pitched (that is: signals in the very low frequency band) sound reproduction by an audio reproduction system or the like a sub-harmonics generator is used to create this low-pitched signal. In this way a lower pitch signal is created then is present in the incoming signal.

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A disadvantage of the known sub-harmonics generator and the known bandwidth extension device is that the amplitude of the sub-harmonics generator is not linear with the input voltage. Known sub-harmonics generators usually clip the input signal and then divide the signal by two for example with a flip-flop, also for example a phase-locked loop is used to obtain the sub-harmonics.

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It is an object of the invention to improve such a bandwidth extension device and to obtain such a bandwidth extension device, which is simpler. To this end a first aspect of the invention provides a bandwidth extension system as defined in claim 1. In this way a bandwidth extension system is obtained which supplies a low pitched signal part with an amplitude proportional with the original signal.

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Further the created sub-harmonics have no discontinuities instead of the sub-harmonics of the prior art bandwidth extension device have.

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Embodiments of the invention are described in the dependent claims.

The invention and additional features, which may optionally be used to implement the invention to advantage, will be apparent from and elucidated with reference to the examples described below and hereinafter and shown in the figures. Herein shows:

Fig. 1 an example of a bandwidth extension device according to the invention,

Fig. 2 first diagrams of the harmonics streams of a signal in the frequency domain,

Fig. 3 second diagrams of harmonics streams of a signal in the frequency domain,

Fig. 4 a second example of a bandwidth extension device according to the invention,

Fig. 5 a third example of a bandwidth extension device according to the invention, and

Fig. 6 an example of an audio reproduction system according to the invention.

Figure 1 shows an example of a bandwidth extension device BD according to the invention. On an input I the bandwidth extension device receives an input signal, for example an audio signal. The input is coupled to a first and a second band-pass filter BPF11 respectively BPF12. From the (narrow-band) input signal two band-limited parts are taken, for example one of 300-600 Hz (BPF11) and one of 300-450 Hz (BPF12).

The output of the band-pass filter BPF11 is coupled to a harmonics generator HG1 and the output of the band-pass filter BPF12 is coupled to a harmonics generator HG2.

The two harmonics generators HG1, resp. HG2 produce two separate streams of harmonics of the selected frequency bands. Frequency components in the first band will be extracted as if the lowest harmonic in the narrow-band signal is the second one, frequency components in the second band will be extracted as if the lowest harmonic in the narrow-band signal is the third one, in this example.

The output of the harmonics generator HG1 is coupled to an input of switching means SM and the output of the harmonics generator HG2 is coupled to the other input of the switching means. The output of the switching means is coupled via a band-pass filter BPF2 to an output O of the bandwidth extension device BD.

It is not necessary that the filtering (BPF2) is equal for both branches, therefore instead of the band-pass filter BPF2 after the switching means it is also possible to have two separate band-pass filters placed in both branches just before the switch means SM.

To decide which of the two harmonics streams in the frequency domain is the most appropriate one analyze means AM are used. The analyze means supply as decision signal a signal ss to the switching means SM. The analyze means receive from both harmonics generators the output signals, and further the analyze means receive the input  
5 signal from the input I and make a decision on the basis hereof.

Of course this decision is not valid for the whole excerpt, so this "best fit decision" should be made every so many samples. Two examples of harmonics streams in the frequency domain are given in Figures 2 and 3.

10 It appeared that it is not necessary to choose which of the harmonics generator gives the best results, when dealing with unvoiced speech. For ease in this example unvoiced speech is treated the same as voiced speech.

To save computing time, the FFT can be used, which means that the number  
15 of samples within the input signal should be a power of 2.

A possible way to decide whether two signals contain similar information is to take their cross-correlation function. Two signals with similar information are maximally correlated with each other.

20 The above can be used to select the harmonics stream in the frequency domain, which has the highest correlation with the narrow-band input signal. The harmonics stream consists of a fundamental and its higher harmonics. If the higher harmonics of the narrow-band signal are (roughly) the same as those of one of the harmonics streams, then that stream will most likely contain the right sub-harmonics too. This is in principle only valid for  
25 voiced speech.

Figure 2 shows an example of the harmonics streams in the frequency domain. A wide-band (1) signal is filtered to obtain a narrow-band signal (2). Of this signal the first frequency component (3) is taken to generate two streams of harmonics, one as if this  
30 component was the second harmonic of the wide-band signal (4a) and one as if it were the third (4b). Comparison of the plot (2) with plots (5a) and (5b) define which stream is most correlated and will most probably contain the right sub-harmonics (6a) and (6b). In this case (6b) fits best.

For decision not the whole spectra are used. All signals in consideration are therefore band-limited from 300 to 1200 Hz.

Since the energy of the harmonics streams is not equal, it can be necessary to have some kind of normalization. This can be done by dividing both cross-correlation functions by the square root of the harmonics streams' auto-correlation function of so called lag zero.

All processing such as filtering and generating harmonics, introduces delay and phase distortion. Hence the cross-correlation function does not have to be symmetric around the origin. As a decision value we use the maximum of the cross-correlation function.

Figure 3 shows another example of the harmonics streams in the frequency domain. Also in this example the wide band (1) signal is filtered to a narrow-band signal (2). Also here of this signal the first frequency component (3) is taken to generated two streams of harmonics, one as if this component was the second harmonic of the wide-band signal (4a) and one as if it were the third (4b). In this example stream 6a fits best.

Figure 4 shows a second example of a bandwidth extension system BD4. At the input I4 the bandwidth extension device receives an input signal, for example an audio signal. This input I4 is coupled to n band-pass filters BPF411 ... BPF41n. The band-pass filters have in this example the following frequency ranges:

BPF411: 300-400 Hz

BPF412: 350-450 Hz

.....

BPF41n: .....

The output of each band-pass filter is coupled to an input of switching means SM4. The output of the switching means is coupled to the harmonics generator HG4. The output of the harmonics generator is coupled via a band-pass filter BPF42 to the output O4 of the bandwidth extension device BD4.

The input I4 is also coupled to analyze means AM4 for analyzing the input signal and supplying a switching signal ss4 to the switching means SM4 and a control signal hs4 to the harmonics generator HG4.

In this way it is possible to create more choosing opportunities the part of lower part of the frequency band for which the creation of sub-harmonics fits best by this input signal.

Figure 5 describes a third example of a bandwidth extension device BD5 according to the invention. At the input I5 the bandwidth extension device receives an signal. Also in this example two signal paths are available. The first one comprising a band-path filter BPF511 and a mixer MIX51 and a second path comprising a band-pass filter BPF512 and a mixer MIX512.

In this example the analyze means AM5 also receive the input signal and the signals after the band pass filters. Here the analyze means supply a first control signal w1 and a second control signal w2. These control signals are supplied to the respective mixers MIX51 and MIX52. The outputs of the mixers are coupled to a summing device SUM5 for summing the two weighted signals and supply via the band-pass filter BPF52 to the output O5 of the band width extension device BD5.

Figure 6 shows an example of an audio reproduction system AS6 comprising a band-width extension device BD6 according to the invention. The audio reproduction system comprises further an input I6 for receiving an signal. The input is coupled to a time delay device TD6 for compensating for the delay of the band -width extension device, the band-width extension device supplies in this example a control signal d6 to the time delay device. The output of the time delay device and the output of the band-width extension device are coupled to a summing device SUM6 for summing the (delayed) origional signal and the band-width extended low frequency signal, at the output ASO6 of the audio reproduction system AS6.

It will be noticed that above the invention has been described on the basis of some examples.

The man skilled in the art is well aware of alternatives within the scope of the invention.

For example it is also possible to send information about the optimal filtering together with the signal to the "receiver". This is clad in the art "non-blind" versus "blind" as described before. In that case the analyze means only have to decode the information about

which filter is optimal for this signal and supply for example the control signals  $w_1$  and  $w_2$  (see figure 5) to the mixers.

- 5 Further instead of using the time domain the invention can also be used in the frequency domain using the inverse Fourier Transform ( $H^* H e^{j\omega}$ )).

Above are examples described (see figure 2 and 3) with divide factors 2 and 3, of course also higher factors can be used.

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